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Final Report For Research Joint Venture
Agmt #INT-90533-RJVA with
UNIVERSITY OF IDAHO
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FOREST ROAD MAINTENANCE STRATEGIES

by

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INTRODUCTION

Considerable work has been done by the World Bank to create a series of models for use in developing countries to optimize road maintenance strategies with respect to vehicle operating costs. This model, the Highway Design and Maintenance Model (HDM III) predicts road deterioration of paved or unpaved roads given traffic volume, road material, environmental, and road prism/geometry information [1].

With a projected traffic type and volume, the model generates road roughness and material loss information. If a certain maintenance strategy is proposed and the costs of the elements of the maintenance are known, the costs of maintenance can be projected for any analysis period. In addition to maintenance costs, vehicle operation costs taken as a function of road roughness, and the other road inputs also be predicted, assuming certain vehicle operating characteristics are estimated.

Changing the maintenance to a higher level (thereby increasing costs), results in lower road roughness. This lower road roughness decreases deterioration and operating costs of the vehicles using the road. The Model can compare various maintenance strategies and their resulting costs to vehicle operation costs. Economically, the Model balances the incremental benefits of decreased vehicle costs to the incremental costs of a higher maintenance level. The "best net present worth" strategy can then be estimated from all proposed maintenance strategies.

OBJECTIVES

The two objectives for this study were as follows:

1. Evaluate the HDM III Model for use as a tool to determine costs of various road maintenance strategies designed to minimize sediment yield.

2. Determine the effort required to modify the HDM III Model to include analysis of Forest Service road maintenance strategies to minimize sediment yield.

EVALUATION OF THE HDM III MODEL

The HDM Model uses empirical and causal relationships to predict road deterioration. These relationships were developed from extensive research in certain third-world countries specifically Brazil, India and Kenya. Although the model has been designed for transferability to other regions, parameters used in the relationships must be verified for the specific regions where the model will be used. Countries where the HDM Model has been used include, Canada [2], Sweden [3], New Zealand [4], and many other developing countries [5].

Many of the applications of the Model in develop countries are of road systems where flexible pavement make up a majority of the road construction. Since 95% of all Forest Service roads are unpaved, only the unpaved portion of the Model is examined in this report.

roughness determination

The HDM Model uses road data readily accessible to the Forest Engineer/Maintenance Foreman to initialize the program. Link characteristics such as length, curvature, grade and material along with estimates of the road link's maximum, minimum and initial roughness are required as input. Yearly traffic volume predictions are also required as input. These traffic volume predictions can be easily changed to reflect different scenarios of resource use.

Using the inputs described, the model projects an average yearly road roughness parameter in either QI units or IRI units for the analysis period specified. These roughness parameters are a primary factor in determining vehicle operating costs and maintenance costs. The roughness function is a combination of empirical and causal relationships the parameters of which have been determined from Brazilian Data. Because the types of road material, climate and environmental factors are different between unpaved roads in Brazil and the USA, the empirical relationships must be recalibrated especially since the Brazilian Data does not reflect freezing/thaw type conditions. Examination of the causal type relationships should also be conducted and field tested for transferability from tropical to more temperate zones.

Evidence from application of the HDM Model's roughness predictions in more temperate climates indicates that the Model's basic assumptions are valid over a wide environmental range. However, as mentioned above, most applications have been for paved roads with relatively little unpaved road applications documented.

material loss

The materials loss predictive equation used in the present model uses most of the same inputs as the roughness relationship, with the exception of differentiating between traffic type. Basically the model predicts the same materials loss from a passenger vehicle as from a loaded logging truck [6]. Various studies done by the Forest Service specifically **Lund** [7] in 1977, dispute this. **Lund's** estimate for materials loss due to a loaded logging truck was equivalent to the loss caused by seven passenger type vehicles.

Paterson [8] delineates a new form for materials loss relationships which incorporates Lund's research with the Brazilian data. This relationship has a factor which is the fraction of heavy vehicles in the traffic flow. Replacement of the present relationship with Paterson's in the HDM Model is anticipated.

Because the materials loss relationship is instrumental in deciding the time for resurfacing (if resurfacing is part of the maintenance strategy) and also affects roughness, it is extremely important in the determination of maintenance costs. The fact that logging trucks are a major part of the traffic volume of some of the Regions, investigation into the materials loss relationship especially as it relates to traffic type is essential.

vehicle operating costs

The vehicle operating cost section of the HDM Model has been the most widely used and verified portion of the Model. The present parameter values used in the **VOC** section are also derived from Brazilian Data. The **VOC** submodel can also be run independently from the deterioration part of the model. Since the types of vehicles observed in the Brazilian Studies do not differ substantially from those operating on forest roads, calibration would not require substantial effort. The one exception would be operating cost data for loaded and unloaded logging trucks.

The Forest Service through its San Dimas Facility is actively investigating updating logging truck operating costs especially in regard to variable tire pressure applications. Previously, the Forest Service developed a Logging Road Handbook (BGN Study Dec. 1960) [9] which was used to estimate the effect of road design on hauling costs. The truck performance curves used in the handbook have been updated several times during the last thirty years. However, the handbook is still the basis of many computer models used for network analysis.

A full scale logging truck operating cost, unpaved/paved road deterioration test was also conducted by the Forest Service in cooperation with other Federal Agencies at the Waterways Experiment Station in 1987. Results of this test are being evaluated at the present time and should become available sometime this next year (1991).

Other truck operation/network models have been used by the Forest Service notably PC TRUCK developed by Oregon State U [10]. Comparison with the default values (closest heavy truck to a logging truck) from the **VOC** Model and the PC TRUCK Model indicate the **VOC** Model's operating costs are estimated consistently lower.

The Canadian Study [3] compared predictions of vehicle operating costs from the presently used HUBAM model and the **VOC** for four types of vehicles. The comparisons indicated limited agreement. However the conclusions in the report, supported calibration and use of the HDM Model over presently used analyses especially since the economic factors for vehicle maintenance are considerably between Brazil and Canada. They conclude "Although a significant amount of work will be required to adapt and calibrate the **VOC** Model so as to accurately reflect the present Canadian vehicle technology and economic environment, we consider this exercise will be much easier than starting from where the World Bank research first began".

maintenance strategies

The HDM Model can be adapted to almost all types of Forest Service maintenance for unpaved roads. Provisions are made for grading on a prescribed time interval (days) or grading when the road reaches a prescribed roughness. Regraveling can be specified on the basis of gravel thickness, that is, one can specify regravelling when the surface gravel thickness decreases to a given level. Spot regraveling can be stipulated when gravel thickness reaches a certain level for any segment of the road link. Routine maintenance (corresponding to a base level of maintenance) is always assumed to be carried out.

Costs of these operations are input by units of $/mile for grading, $/mile/yr for routine maintenance, and $/cuyd for spot regraveling and gravel resurfacing.

Combinations of these options and the ease of obtaining the unit costs for the options, allow one to match most of the typical maintenance operations and costs presently used or those projected to be used in the future.

sediment yield

The model in it's present state does not predict sediment yield. However, if a relationship between sediment yield and maintenance strategies could be developed and if an economic measure of sediment impact is available, one could easily incorporate this impact into the model.

An example of this methodology would be to run the model with a proposed maintenance policy, obtaining yearly average roughness and maintenance information. From the roughness and grading/regraveling information, estimate yearly sediment yield and the economic impact of sediment. Rerun the model using the yearly economic costs of sediment yield as an yearly exogenous cost input. Thus, total costs of maintenance, vehicle operation and sediment could be estimated for the analysis period. Finally, one could compare the total costs (routine, grading, graveling, vehicle and sediment) of various maintenance policies to obtain the highest incremental net present worth leading to the determination of an **optimal maintenance policy.**

Perhaps a more realistic application of the Model with sediment impacts involves setting an upper limit on the total amount (lbs) or concentration (gms/l) of sediment yield. Any maintenance option that produces sediment exceeding the set limits would be eliminated from consideration. This procedure negates the need to translate sediment yield into economic terms but still preserves the option of obtaining an **optimal maintenance policy under sediment constraints.** One could set various sediment limits on each link of the road system so if a road segment was close to sensitive water quality area (such as a live stream crossing) a much lower sediment limit could be set.

The previous examples of potential Model applications incorporating sediment impacts are based on finding a relationship between sediment yield and roughness/grading. Roughness is generally measured using an accelerometer mounted in a vehicle (or mounted in a trailor towed behind a vehicle). The accelerometer output is calibrated using a road with known roughness values. Sediment yield may be more a function of road rutting (generally longitudinal type ruts) than transverse type changes in the road surface [11]. Since the unpaved surface deterioration is based only on roughness and materials loss, investigation into prediction of unpaved road surface rutting may be warranted.

MODEL CHANGES FOR FOREST SERVICE APPLICATION

Changes to the HDM Model to fit Forest Service needs include:

1. Calibration of the road roughness submodel to reflect the different environmental and materials conditions from Brazil (especially the effects of freezing and snow conditions) for the unpaved portion of the model.

2. Examination of the relationship between materials loss and the type of vehicle traffic. The present Model relationship makes no distinction between material loss from regular passenger car or pickup traffic verses a loaded or unloaded logging truck. Forest Service field tests indicate a substantial difference in materials loss for a logging truck vs. other type traffic. Other ongoing research and field data may be available to help verify or change this function without a great deal of additional field testing. Specifically Paterson's [8] new materials loss relationship with a factor of the fraction of heavy trucks in the traffic.

3. Calibration of the parameters in the **VOC** Submodel for loaded logging trucks. As noted above, there has been a substantial amount of research in the validity of the **VOC** Model. Using previous research on VOC Costs along with current research, the **VOC** Model should be relatively easily calibrated as compared to the deterioration relationships.

4. Sediment yield as a function of maintenance and road roughness has not been adequately evaluated for forest roads. Recent research [11] indicates a correlation between rutting (longitudinal ruts) and sediment yield. Extension of this work to include sediment yield as a direct function of road surface rutting, roughness and road maintenance is the area where the greatest amount new field research is necessary. Burroughs [12] has proposed addition field research (in summer 1991) to address these relationships.

5. Evaluation of the reduction of roughness and materials loss due to logging trucks or other vehicles using **variable tire pressure.** Preliminary results from tests conducted by numerous Forests [13] indicate a

substantial reduction in road grading because of the use if low pressure tires on loaded and unloaded logging trucks. This reduction of road grading for the same level of road roughness may reduce sediment impacts as well as maintenance cost without great increases in vehicle cost.

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Appendix 1

Input information for the HDM Model

Example of the application of the HDM Model to a sample of unpaved roads in the Nez Perce NF.

Road surface material and road geometrical data was taken from studies done in the Horse Creek drainage in 1981-83. Most maintenance and traffic volume information was taken from a response by Region 1 Engineering to a request from Washington Office Engineering for road maintenance information in the fall of 1990.

Only maintenance levels 3 & 4 for graveled roads are considered. Routine maintenance cost information was obtained directly from the Nez Perce Forest. All maintenance options considered in this example have been estimated to preserve the road for the given level of service over the analysis period.

Vehicle information was taken from the HDM Default Data and represents Brazilian and US. vehicle operating costs.

Input Data

The following illustrates the type of road and cost data necessary to run the HDM Model. Road data was abstrated from information supplied by Region 1 and the Nez Perce NF. A gravel road in the Nez Perce Forest was hypothesised to represent the average road in level 3 and level 4 maintenance categories.

economic data

Grading	80.0	$/km
Spot regavelling	15.7	$/m^3
Gravel resurfacing	13.1	$/m^3
Routine maintenance	300.0	$/km/yr

unpaved road characteristics

Miles of road		
level 3 type	964.0	km
level 4 type	90.0	km
Environment		
average monthly rainfall	0.953	m/mon
altitude	1692.0	m
Geometry		
rise plus fall (grade data)	26.5	m/km
horizontal curvature	390.0	degrees/km
road width	3.7	m
shoulder width	0.0	m
Condition		
gravel thickness	130.0	mm
inital roughness	55.0	QI

Surface		
	minimum roughness	50.0 QI
	maximum particle size	38.0 mm
	material passing 2.00 mm sieve	45.0 %
	material passing 0.425 mm sieve	60.0 %
	material passing 0.075 mm sieve	14.5 %
	plasticity index	0.0 %
	maximum roughness	150.0 QI
Base/Subgrade		
	minimum roughness	60.0 QI
	maximum particle size	38.0 mm
	material passing 2.00 mm sieve	45.0 %
	material passing 0.425 mm sieve	60.0 %
	material passing 0.075 mm sieve	14.5 %
	plasticity index	0.0 %
	maximum roughness	150.0 QI
History		
	gravel age	0.0 yr.

maintenance strategies

Strategy 0: (Base Alternative)
- a. grading interval ..... every 100 days
- b. regravelling .....thickness decreases to 1 in.
- c. gravel characteristics .....same as original surface
- d. routine maintenance.....yearly

Strategy I:
- a. grading interval ..... every 100 days
- b. spot regravelling .....30 % of gravel loss replaced
- c. regravelling .....thickness decreases to 1 in.
- d. gravel characteristics.....same as original surface
- e. routine maintenance .....yearly

Strategy II:
- a. grading interval ..... every 200 days
- b. regravelling .....thickness decreases to 1 in.
- c. gravel characteristics.....same as original surface
- d. routine maintenance .....yearly

Strategy III:
- a. grading interval..... every 200 days
- b. spot regravelling .....30 % of gravel loss replaced
- c. regravelling .....thickness decreases to 1 in.
- d. gravel characteristics .....same as original surface
- e. routine maintenance.....yearly

Strategy IV:
- a. grading.....when roughness reaches 125 QI
- b. regravelling.....thickness decreases to 1 in.
- c. gravel characteristics.....same as original surface
- d. routine maintenance.....yearly

Strategy V:
- a. grading.....when roughness reaches 125 QI
- b. spot regravelling.....30 % of gravel loss replaced
- c. regravelling.....thickness decreases to 1 in.
- d. gravel characteristics.....same as original surface
- e. routine maintenance.....yearly

Strategy VI: (do little maintenance option)
- a. no grading
- b. only minimum routine maintenance
- c. complete reconditioning on a ten year cycle
- d. regravelling.....bring gravel thickness to 4 in.
- f. total reconditioning cost.....$30000/mi

vehicle operating cost inputs

All vehicle operating cost information was taken from Brazilian Data with the exceptions for labor rates and new vehicle costs. These were changed to reflect US values. The two vehicles selected for this example were the closest to typical vehicles using forest roads.

Operating characteristic	Utility Vehicle	Articulated Heavy Truck
HP Metric	61	240
Gross vehicle weight (tons)	2.1	38.0
EQX4 (Number of equivalent standard axles per veh)	0	12.87
VAXLES (Number of axles per vehicle)	2	4
New Vehicle Cost $	15000.	71079.
New Tire Cost $	120.	350.
Maintenance Labor Cost $/hr	15.	15.
Crew Cost $/hr	10.	10.
Interest Cost on New Veh. %	12.	12.
Gas Cost $/liter	.39	.39
Diesel Cost $/liter	.37	.37
Lubricants Cost $/liter	1.22	1.22
Km Driven/yr	40000	70000
Vehicle Life Yrs	5	10
Hrs Driven/yr	2500	2400

vehicle traffic volume

Traffic ADT's for level 3 roads were taken as 50 veh/day and 75 veh/day for level 4 roads. Seasonal adjustments to the traffic volume was assumed to be a percentage of the year the road was estimated to be open for traffic.

Logging trucks: The first example run uses both loaded and unloaded logging trucks as the only traffic using the road. The traffic ADT was divided by assuming half the ADT was loaded trucks (25 ADT) and half unloaded trucks (25 ADT). These values were then adjusted for the road operating season. For example, if the road was estimated to be open for six months, the ADT was cut in half.

Utility Vehicles: The utility vehicle ADT was exactly the same as the logging truck example. Only this class of a vehicle made up the entire ADT. Seasonal adjustments to the ADT were also made.

Appendix 2

Sample Results

The following pages represent a sample of the types of output one could obtain from the model. The basic outputs can be divided into economic and road surface information.

road surface outputs: The information concerning the road surface would generally be :

1. the thickness of gravel at the end of a year
2. the average yearly roughness
3. the years since the last regravelling
4. the year major capital maintenance was to be done. (regravelling is considered capital maintenance)

Roughness vs time graphs can be easily generated as shown.

economic type data: Basically the economic data is shown in the **costs summary report.** This includes:

1. Construction upgrades (yearly cost)
2. Yearly routine and periodic maintenance costs
3. Total routine and periodic maintenance costs
4. Total of all road costs starting from the beginning of the analysis.

economic comparisons: The model allows one to compare various maintenance strategies with the base strategy using any chosen discount rate. The economic comparison histograms illustrate this comparison at a 6% rate. Alternatives I through VI were compared to alternative 0 and the net present value was determined for each pair. This comparison uses both road maintenance and vehicle operating costs.

For this sample run, alternative 0 had the best relative present worth when compared to all other alternatives at a 6% discount rate. However, alternative 0 did not have the least total maintenance cost, alternative 2 had the least cost.

Other types of comparisons between alternatives can be made, such as finding the optimal strategy for different levels of traffic. The ADT Economic Comparison Chart shows how the present value for the seven options change with ADT levels. The best stratgey for low ADT's might not be best for higher levels as this chart indicates. Alternative IV is best for ADT's around 4 but I is still the best for ADT's above that level.

HDM-.123 REPORT

ANNUAL ROAD CONDITIONS REPORT

DATE 01/21/91

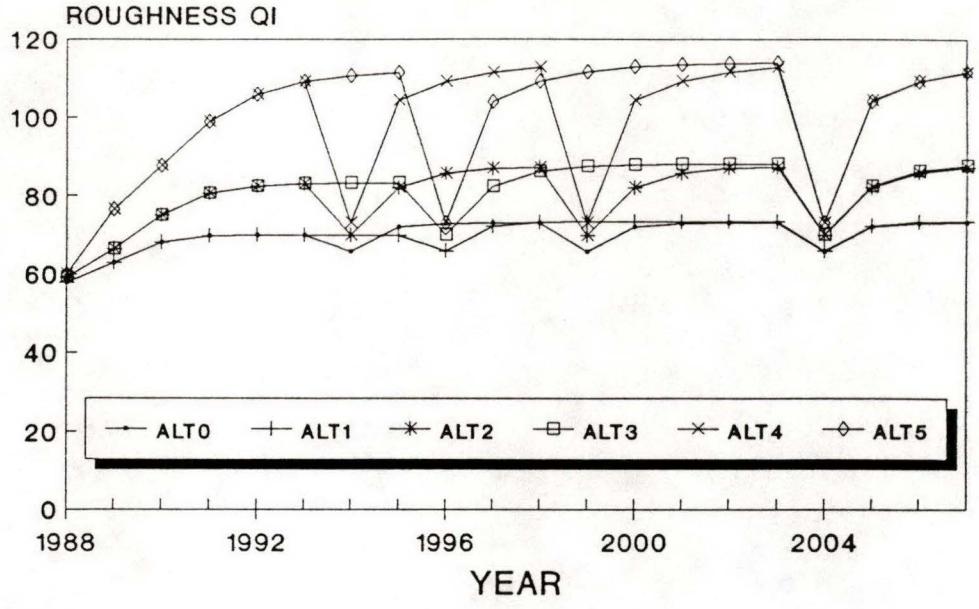
RUN LEVEL 3 ROAD

ROAD CONDITIONS BEFORE MAINTENANCE

LINK-ALT. GRAV-ALTO
SECTION 1

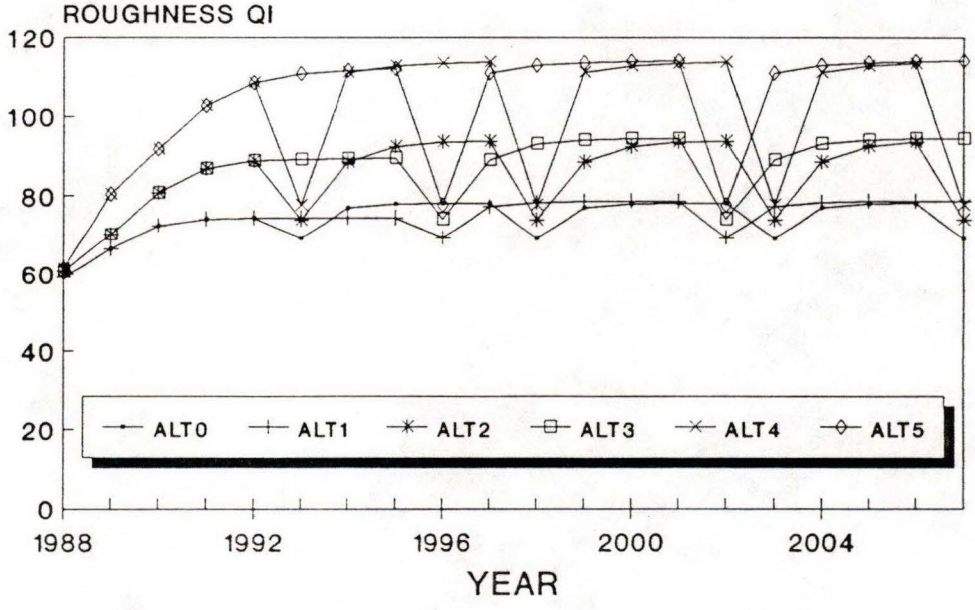
YEAR	TWO-WAY ADT (VPD)	ANNUAL TWO-WAY ESA (THOUS)	YEARS SINCE LAST REGRV	SURF TYPE	PERIODIC MAINT APPLIED	GRAVEL THICKNESS (mm)	MEAN YEARLY ROUGHNESS (IR)
1990	24	112.7	1	GRAV		83	60
1991	24	112.7	2	GRAV		66.1	68.8
1992	24	112.7	3	GRAV	RESU	49.1	77
1993	24	112.7	1	GRAV		82.1	72.1
1994	24	112.7	2	GRAV		65.1	83.2
1995	24	112.7	3	GRAV	RESU	48.2	85.2
1996	24	112.7	1	GRAV		81.2	72.1
1997	24	112.7	2	GRAV		64.2	83.2
1998	24	112.7	3	GRAV	RESU	47.2	85.2
1999	24	112.7	1	GRAV		80.3	72.1
2000	24	112.7	2	GRAV		63.3	83.2
2001	24	112.7	3	GRAV	RESU	46.3	85.2
2002	24	112.7	1	GRAV		79.4	72.1
2003	24	112.7	2	GRAV		62.4	83.2
2004	24	112.7	3	GRAV	RESU	45.4	85.2
2005	24	112.7	1	GRAV		78.4	72.1
2006	24	112.7	2	GRAV		61.5	83.2
2007	24	112.7	3	GRAV	RESU	44.5	85.2
2008	24	112.7	1	GRAV		77.5	72.1
2009	24	112.7	2	GRAV		60.6	83.2

LEVEL 3 ROUGHNESS
MEAN YEARLY BEFORE MAINTENANCE



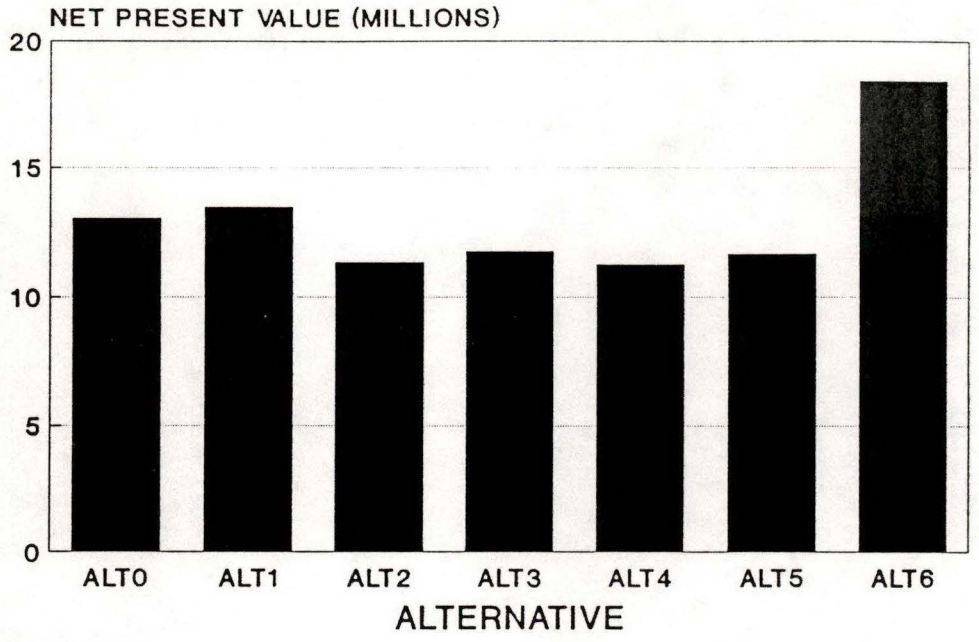
PICKUP

LEVEL 4 ROUGHNESS
MEAN YEARLY BEFORE MAINTENANCE



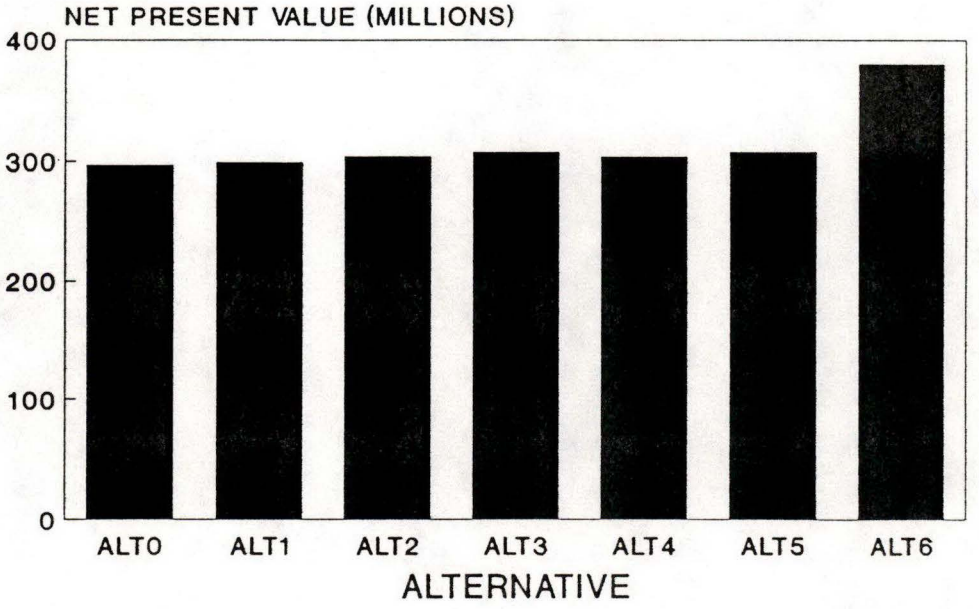
PICKUP

CONSTRUCTION & MAINTENANCE COSTS
LEVEL 3, 6% DISCOUNT RATE



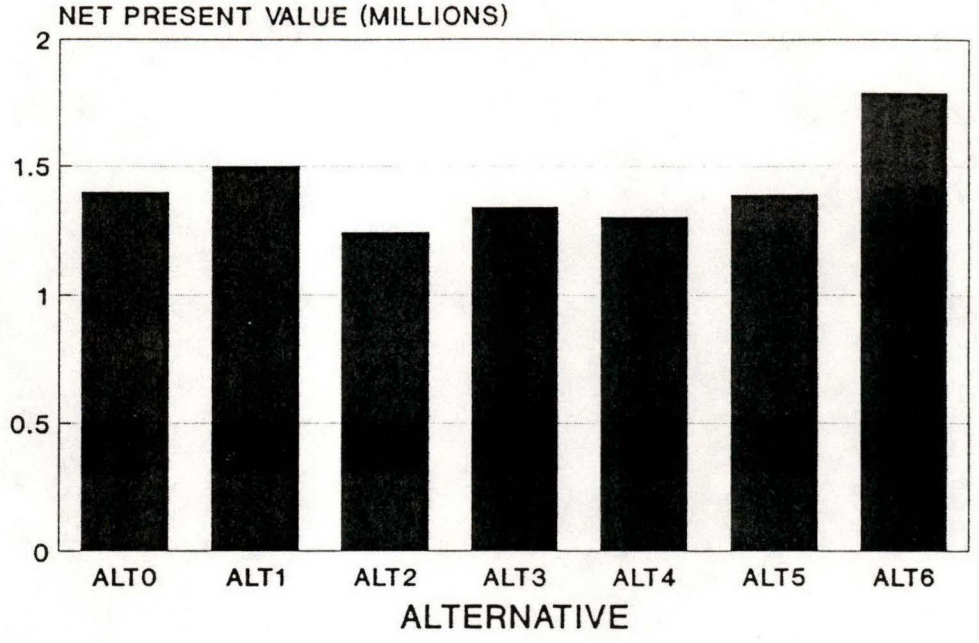
TRUCKS

TOTAL COST
LEVEL 3, 6% DISCOUNT RATE



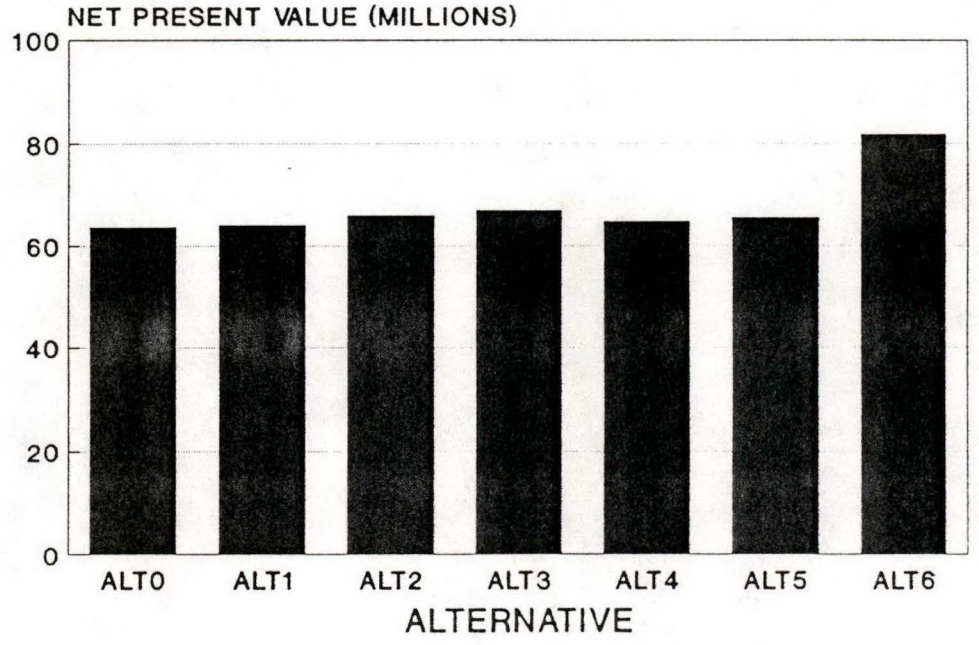
TRUCKS

CONSTRUCTION & MAINTENANCE COSTS
LEVEL 4, 6% DISCOUNT RATE



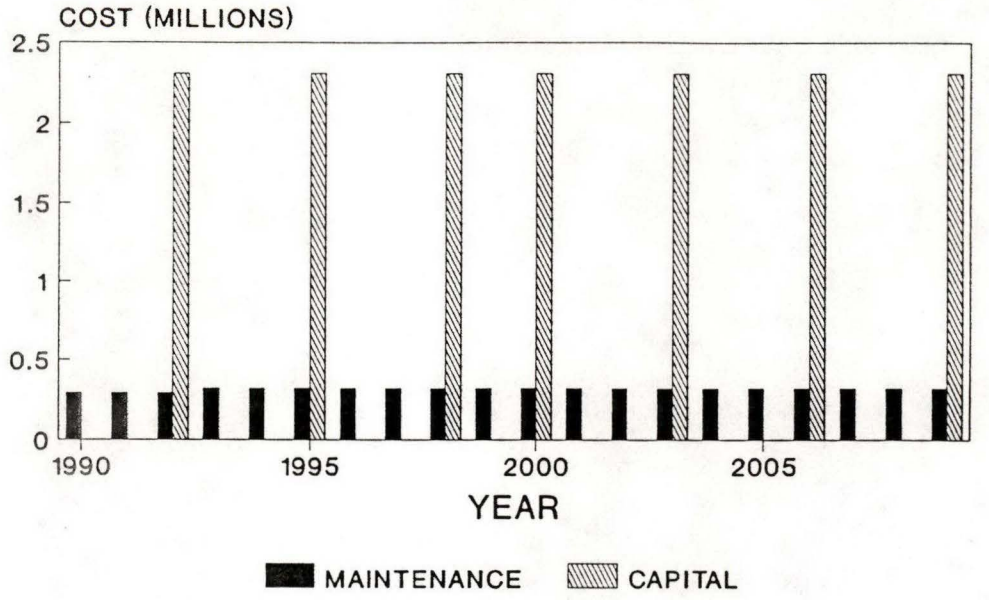
TRUCKS

TOTAL COST
LEVEL 4, 6% DISCOUNT RATE

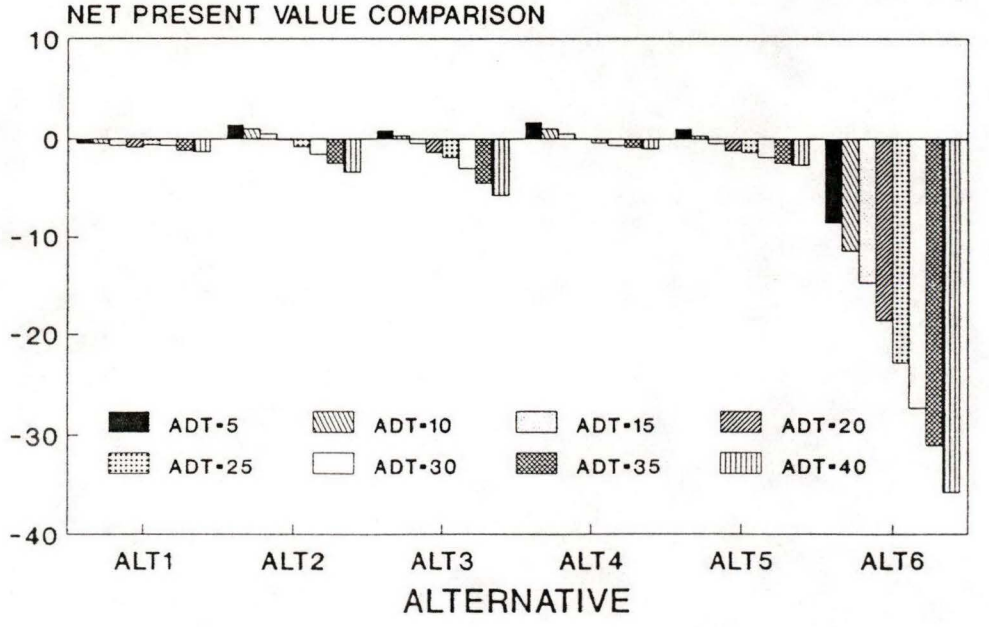


TRUCKS

ECONOMIC COSTS
LEVEL 3 ROAD, ALT 4



ADT ECONOMIC COMPARISON
LEVEL 3 ROAD, 6% DISCOUNT RATE



PICKUPS